An open gate 4H-SiC junction field effect transistor for pH sensing

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Biochemical detection using portable and reliable sensors have important applications in many application fields : homeland security, healthcare, environment and medical monitoning (point of care), food safety, forensic, etc. Field-effect transistors based on silicon nanowires (SiNW-FETs) have been intensely developed over the last years and have proved major promise in label-free, real-time, selective and highly sensitive electrical measurements for biosensing applications [1]. However, issues in term of result reproducibility still exist strongly limitating real – life applications. Notably, SiNWs suffer from a lack of long-term chemical stability in physiological environments resulting in drastic signal drift and changes in the signal-noise ratio [2]–[4]. Hence, replacing the silicon with other semiconducting materials offering inherent chemical robustness, comparable electronic properties as well as biocompatibility to fabricate NW FETs should be required. In this regard, silicon carbide SiC is the complete alternative material of choice. SiC is a wide band gap (2.3–3.3 eV) semiconductor material particularly attractive for highly sensitive devices owing to its chemical inertness in harsh environments including those with high wear, and/or harsh chemicals and high temperatures (>600°C). Besides, our group has compared the long-term stability of Si and SiC NWs under mimicked physiological conditions. The results emphasized a clear superior long-term stability of SiC nanowires over Si nanowires [5]. On this basis, our group has investigated the biomodification of SiC nanostructures and nanowires [6] to perform the electrical detection of DNA hybridization on SiC NW based FETs . SiC exhibits also enhanced biocompatibility proved by the absence of cytotoxic effects after interfacing with different mammalian cell cultures [7]. Moreover, it is easy to functionalize owing to the reactivity of the Si and C terminations on the surface which also allows different types of functionalization. However, to further investigate the sensing performances of these devices, it is necessary to use optimized SiC-based FET devices with very well-suited intrinsic characteristics.

Owing to its distinct advantages, SOI-based ISFETs have been extensively studied in the last decade [8]. Thus, the obvious wafer type on which we can easily fabricate our device would be a silicon carbide on insulator SiCOI taking advantage of the mature understanding of SOI technology and the advanced biosensor applications already realised on SOI wafers. Unlikely silicon carbide on insulator (SiCOI) is not commercialized yet, we decided to fabricate structures using only SiC junctions without the need for a buried oxide. The obvious solution is to form a JFET (Junction field-effect transistor). Thus, this research work introduces a new ion-sensitive field-effect transistor namely the silicon carbide microwire based dual-gate ion-sensitive junction field-effect transistor (4H-SiC-DGISJFET). Figure 1 shows the schematic cross-section representation of the investigated microwire 4H-SiC-DGISJFET. In the case of the 4H-SiC-DGISJFET, the top PN junction connected to the n-type channel from a single side (bottom side – substrate side) is incorporated leaving the other side free and open for the “sensing” application. The n-type layer serves as the sensing layer between two ohmic contacted sources and drains regions. The device is simulated using the 3D ATLAS-SILVACO tool to observe and compare the electrical characteristics with the ones of the fabricated device. The extracted electrical characteristics from the simulation are in agreement with the measured ones on the fabricated device (Fig. 2). Then, the sensing performances in liquid conditions such as pH measurements of the proposed 4H-SiC-DGISJFET have been determined. The detection of voltage modification upon pH changes is performed when top-and-bottom- gate bias is applied. pH measurements show that a large voltage shift up to 719 mV/pH is obtained when the top gate is kept at a fixed potential and the bottom gate is varied. This is an improvement of 6 times over the 120 mV/pH measured using a top-gate sweep with the bottom-gate at a fixed potential. The experimental and simulation results in this work, for the first time, put forward the 4H-SiC-DGISJFET as a new foundry-process-based, producible ion-sensitive FET sensor for biological and chemical applications.

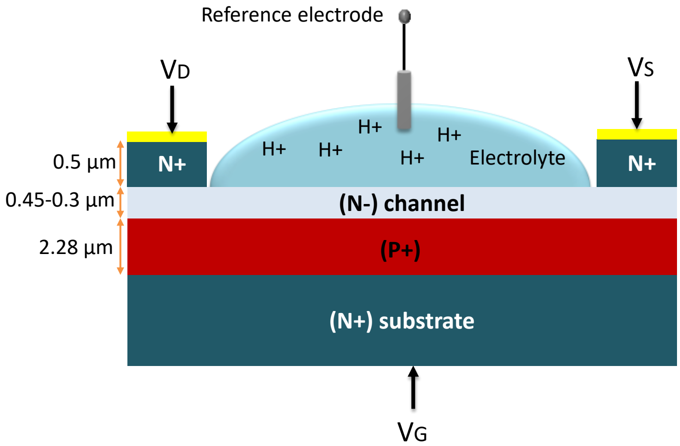

Fig 1. Schematic cross-section representation (not to scale) of the 4H-SiC-DGISJFET. V_S, V_D, and V_G refer to the bias applied to the source, drain, and gate, respectively

(a) (b)

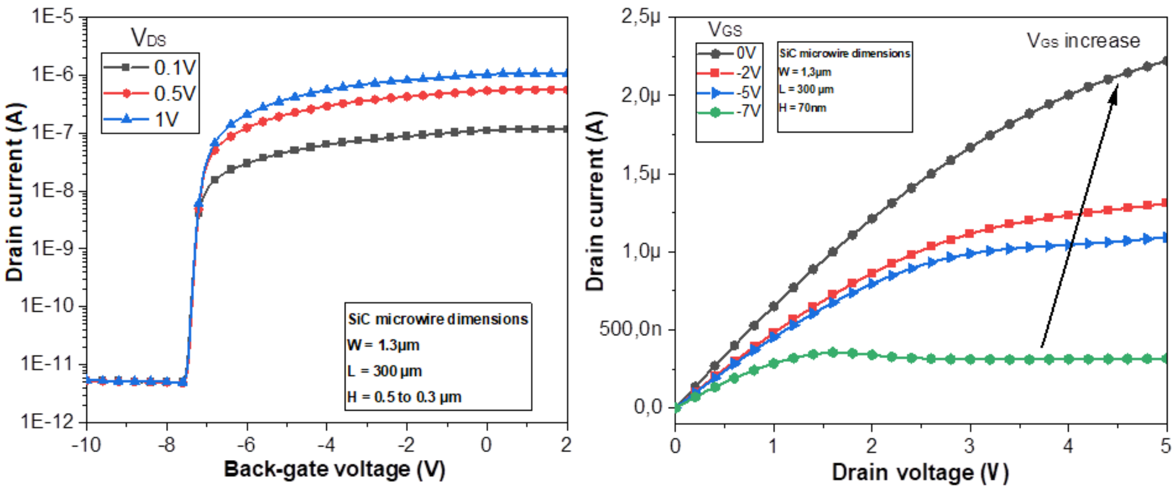

Fig 2. (a) Transfert characteristic in terms of drain current versus back-gate voltage at different drain voltage values 0.1V , 0.5V and 1 V , (b) Output characteristic in terms of drain voltage versus drain current at different gate voltages

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